Wolkite University
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Department of Electrical and Computer Engineering

Wolkite University, College of Engineering and Technology

ECEg-4191 Data Communication and Computer Networks

Chapter Five
Wide Area Networks
Lecture 5.1

Contents

- Introduction
- WAN Switching
- Routing and Routing Algorithms
- WAN Technology Options

Introduction

Similarities to LANs

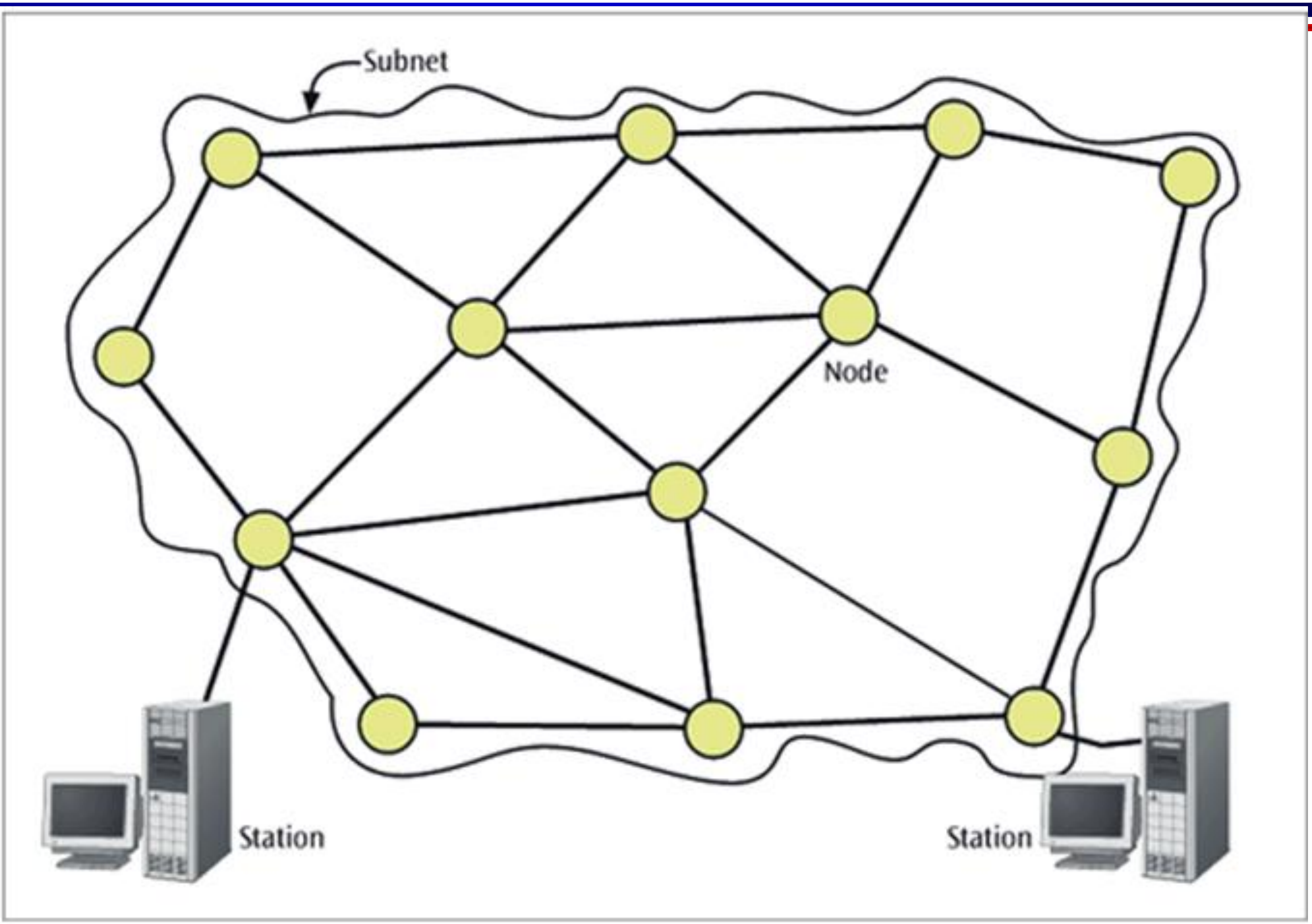
- Interconnect computers.
- Use some form of media for the interconnection.
- Support network applications.

Differences to LANs

- Include both data networks, such as the Internet, and voice networks, like telephone systems.
- Interconnect more workstations, so that any one workstation can transfer data to any other workstation.
- Cover large geographic distances.

WAN Switching

Network subnet, nodes, and two end stations



WAN Switching

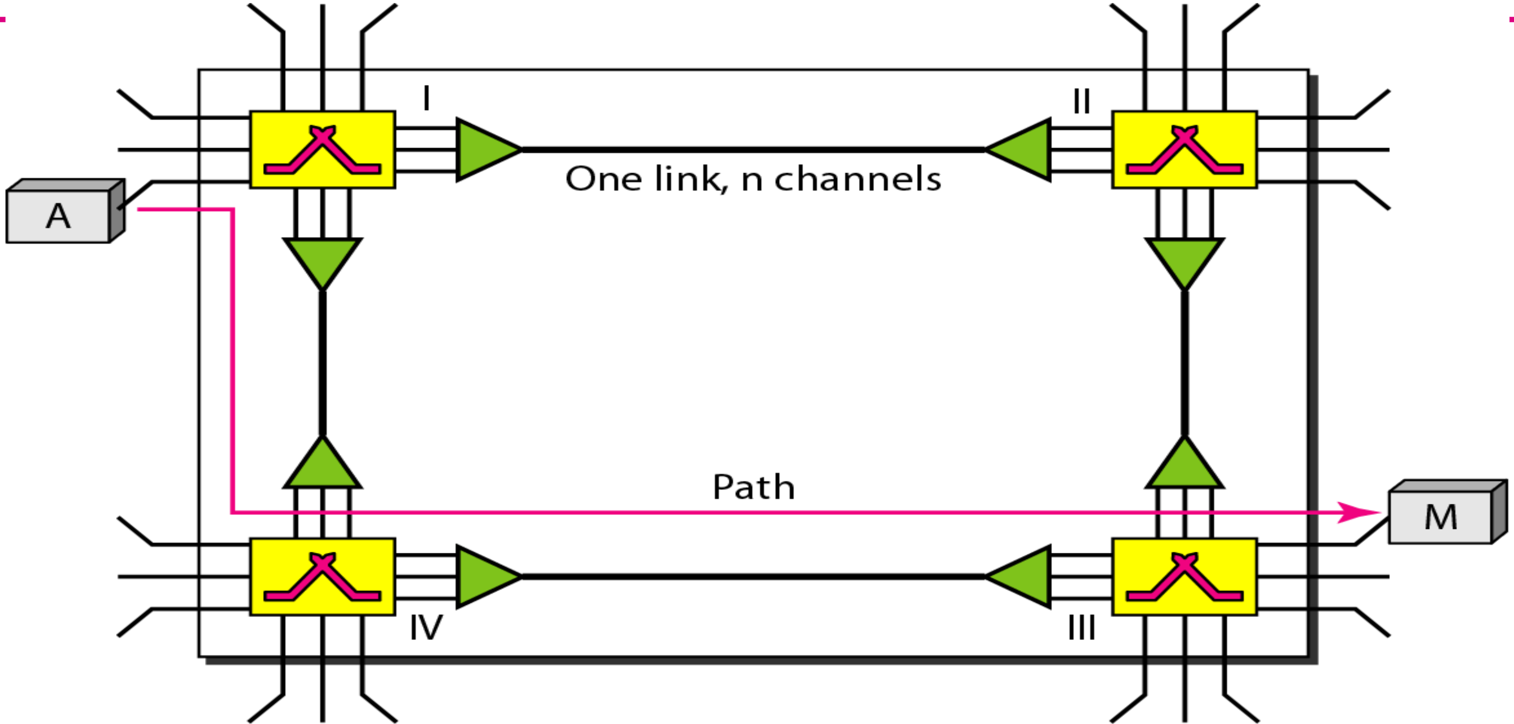
- A switched network consists of a series of interlinked nodes, called switches.
- In a switched network, some of these nodes are connected to the end systems (computers or telephones, for example). Others are used only for routing.

A network categorized by the way it transfers information from one node to another as

1. ***Circuit switched network*** - a network in which a dedicated circuit is established between sender and receiver and all data passes over this circuit. The connection is dedicated until one party or another terminates the connection. The telephone system is a common example.
2. ***Packet switched network*** - a network in which all data messages are transmitted using fixed-sized packages, called packets (datagram and virtual-switched network).
   - Packet-switched networks can further be divided into two subcategories-virtual-circuit networks and datagram networks

Circuit-switched Networks

- A circuit-switched network consists of a set of switches connected by physical links.
- A connection between two stations is a dedicated path made of one or more links.
- However, each connection uses only one dedicated channel on each link. Each link is normally divided into n channels by using FDM or TDM.



Circuit-switched Networks

- As shown above, when end system A needs to communicate with end system M, system A needs to request a connection to M that must be accepted by all switches as well as by M itself.
- This is called the setup phase; a circuit (channel) is reserved on each link, and the combination of circuits or channels defines the dedicated path.
- After the dedicated path made of connected circuits (channels) is established, data transfer can take place.
- After all data have been transferred, the circuits are torn down.

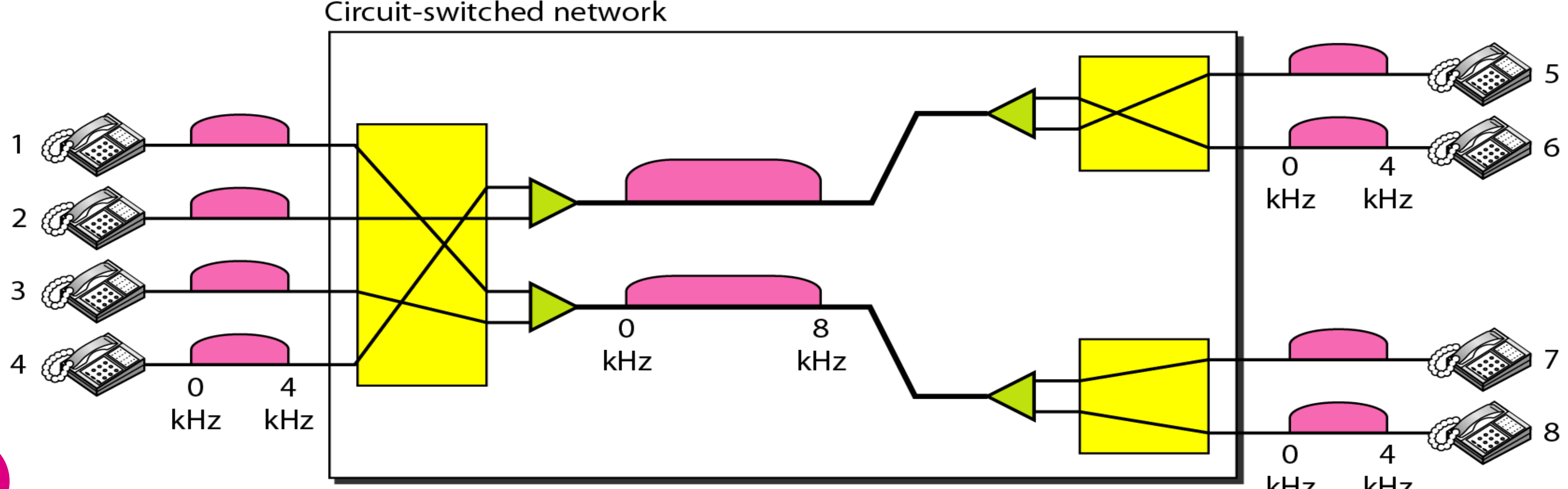
More points on Circuit-switched Networks…

1. Circuit switching takes place at the physical layer.
2. Before starting communication, the resources, such as channels (bandwidth in FDM and time slots in TDM), switch buffers, switch processing time, and switch input/output ports, must remain dedicated during the entire duration of data transfer until the teardown phase.
3. Data transferred between the two stations are not packetized (physical layer transfer of the signal). The data are a continuous flow sent by the source station and received by the destination station, although there may be periods of silence.
4. There is no addressing involved during data transfer. The switches route the data based on their occupied band (FDM) or time slot (TDM). Of course, there is end-to-end addressing used during the setup phase.

Circuit-switched Networks

Example

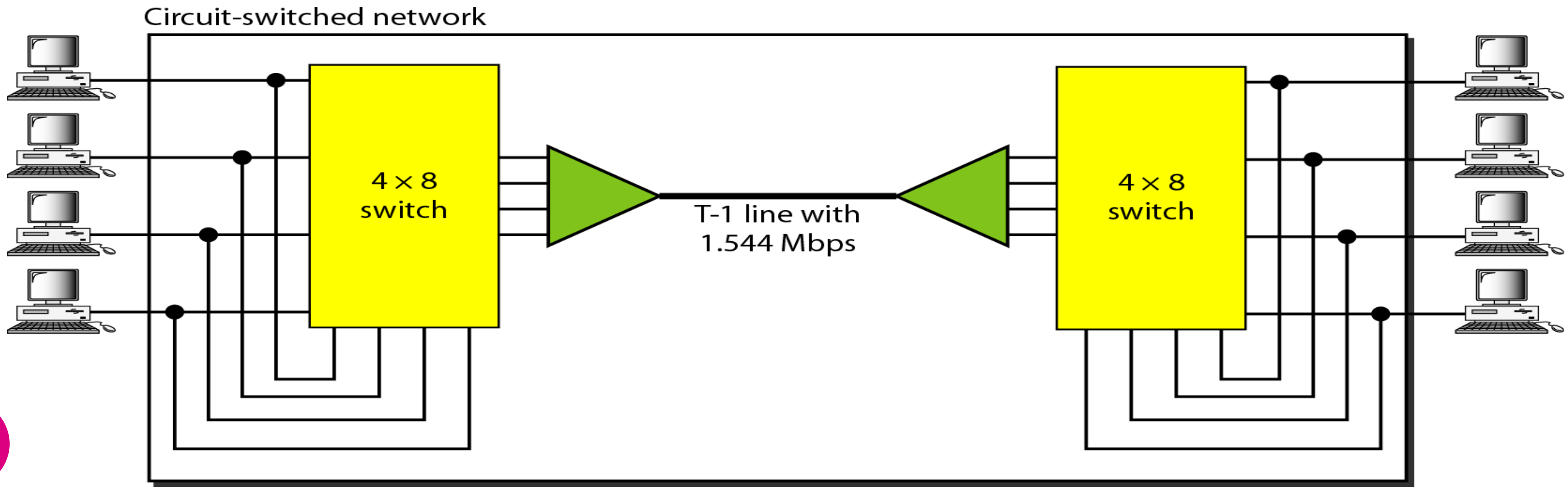
- As a trivial example, let us use a circuit-switched network to connect eight telephones in a small area. Communication is through 4-kHz voice channels. We assume that each link uses FDM to connect a maximum of two voice channels. The bandwidth of each link is then 8 kHz. The figure below shows the situation. Telephone 1 is connected to telephone 7; 2 to 5; 3 to 8; and 4 to 6. Of course the situation may change when new connections are made. The switch controls the connections.



Circuit-switched Networks

Example 2

- As another example, consider a circuit-switched network that connects computers in two remote offices of a private company. The offices are connected using a T-1 line leased from a communication service provider. There are two 4 × 8 (4 inputs and 8 outputs) switches in this network. For each switch, four output ports are folded into the input ports to allow communication between computers in the same office. Four other output ports allow communication between the two offices.

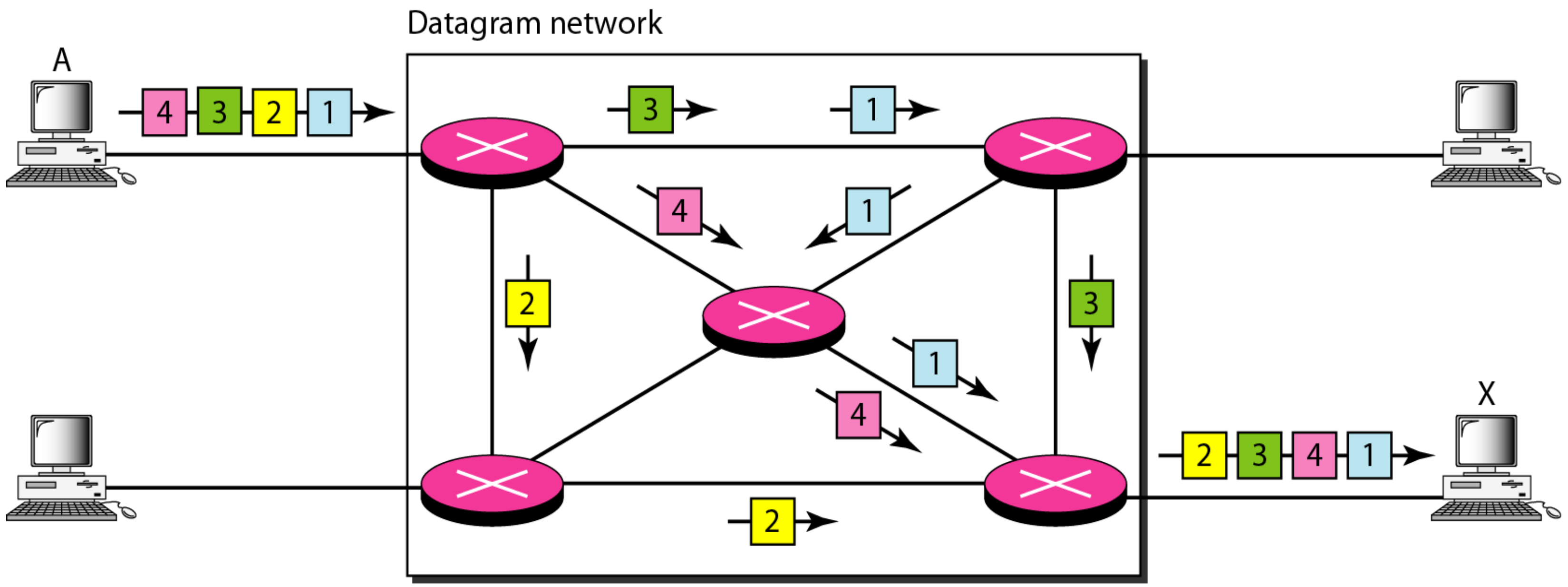


Packet Switched Networks: DATAGRAM NETWORKS

- In data communications, if the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size.
- The size of the packet is determined by the network and the governing protocol.
- In packet switching, there is no resource allocation for a packet. This means that there is no reserved bandwidth on the links, and there is no scheduled processing time for each packet.
- Resources are allocated on demand. The allocation is done on a first-come, first-served basis. – **statistical multiplexing**
- When a switch receives a packet, no matter what is the source or destination, the packet must wait if there are other packets being processed.

Packet Switched Networks: DATAGRAM NETWORKS

- In a datagram network, each packet is treated independently of all others.
- Packets in this approach are referred to as datagram.
- Datagram switching is normally done at the network layer.



Packet Switched Networks: DATAGRAM NETWORKS

- In the previous figure, all four packets (or datagrams) belong to the same message, but may travel different paths to reach their destination.
- This is so because the links may be involved in carrying packets from other sources and do not have the necessary bandwidth available to carry all the packets from A to X.
- This approach can cause the datagrams of a transmission to arrive at their destination out of order with different delays between the packets.
- Packets may also be lost or dropped because of a lack of resources.

Packet Switched Networks: DATAGRAM NETWORKS

- In most protocols, it is the responsibility of an upper-layer protocol to reorder the datagrams or ask for lost datagrams before passing them on to the application.

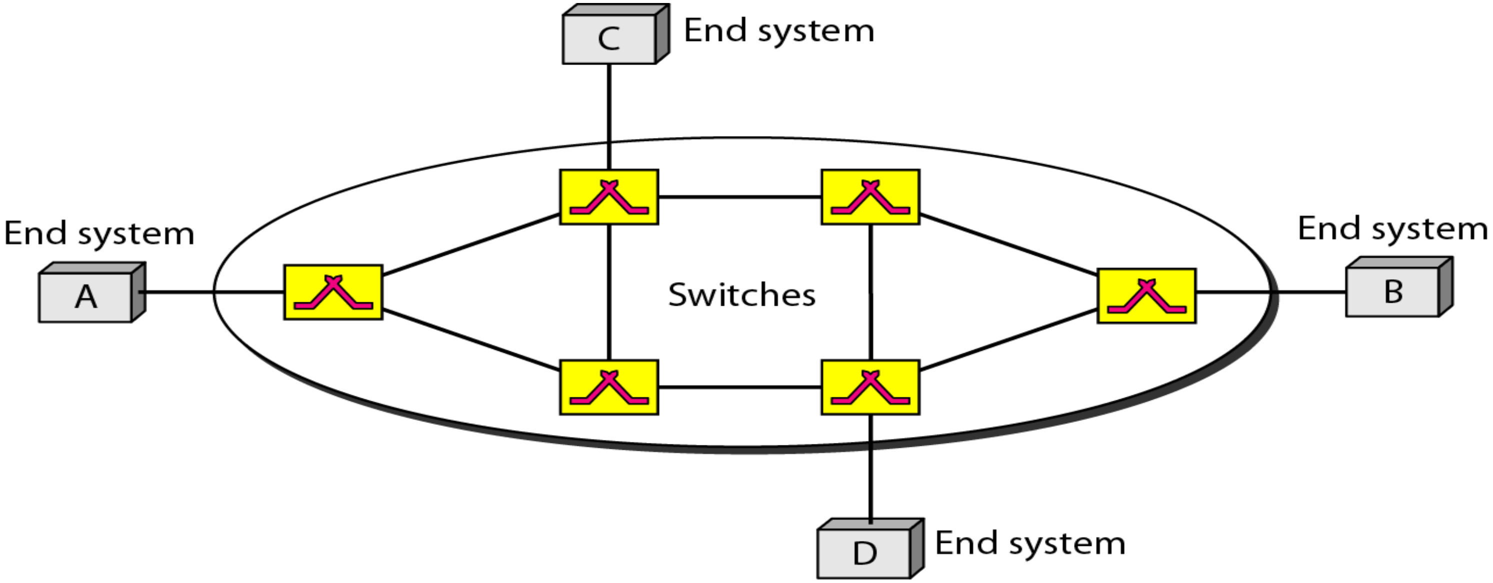
- The datagram networks are sometimes referred to as connectionless networks.
- The term connectionless here means that the switch (packet switch) does not keep information about the connection state.
- There are no setup or teardown phases.
- Each packet is treated the same by a switch regardless of its source or destination.

Packet Switched Networks: Virtual-circuit Networks

- A virtual-circuit network is a cross between a circuit-switched network and a datagram network. It has some characteristics of both.

1. As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
2. Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
3. As in a datagram network, data are packetized and each packet carries an address in the header.
    - However, the address in the header has local jurisdiction (it defines what should be the next switch and the channel on which the packet is being carried), not end-to-end jurisdiction.
    - How the intermediate switches know where to send the packet if there is no final destination address carried by a packet? Using virtual-circuit identifiers.
4. As in a circuit-switched network, all packets follow the same path established during the connection.
5. A virtual-circuit network is normally implemented in the data link layer, while a circuit-switched network is implemented in the physical layer and a datagram network in the network layer.

Virtual-circuit Networks

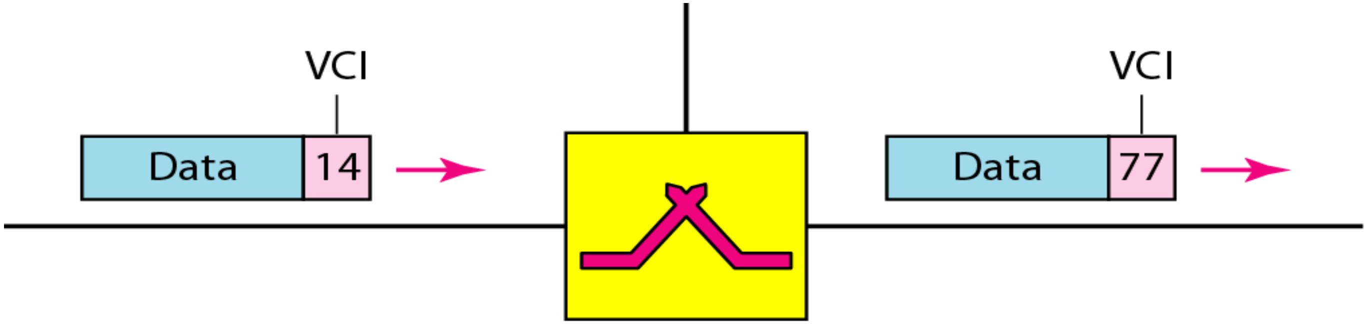


- The above figure is an example of a virtual-circuit network. The network has switches that allow traffic from sources to destinations.
- A source or destination can be a computer, packet switch, bridge, or any other device that connects other networks.

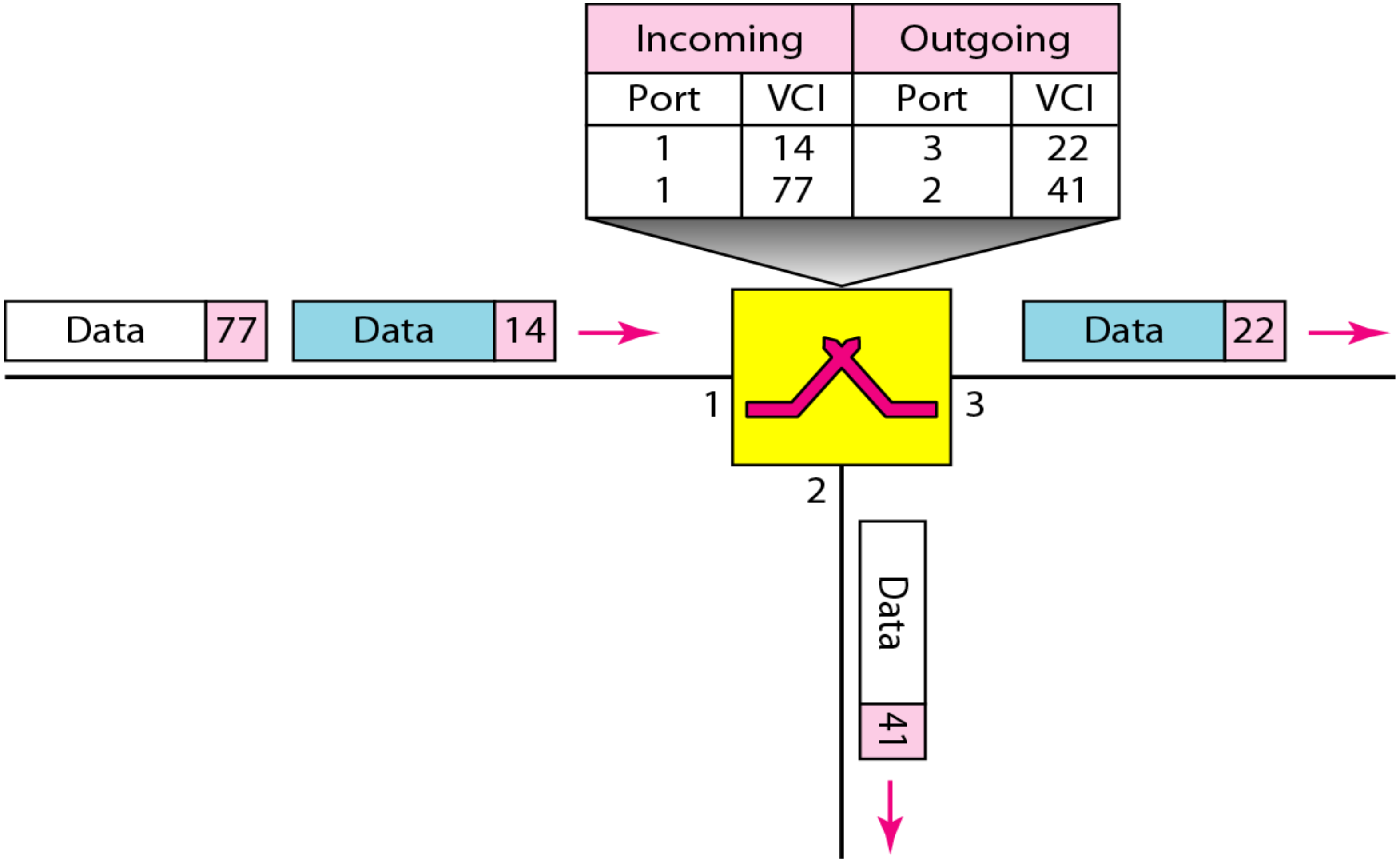
Addressing

- In a virtual-circuit network, two types of addressing are involved: global and local (virtual-circuit identifier).
- *Global Addressing*
  - A source or a destination needs to have a global address-an address that can be unique in the scope of the network or internationally if the network is part of an international network.
  - However, a global address in virtual-circuit networks is used only to create a virtual-circuit identifier.

- *Virtual-Circuit Identifier*
- The identifier that is actually used for data transfer is called the virtual-circuit identifier (VCI).
- A VCI, unlike a global address, is a small number that has only switch scope; it is used by a frame between two switches.
- When a frame arrives at a switch, it has a VCI; when it leaves, it has a different VCI.
- Note that a VCI does not need to be a large number since each switch can use its own unique set of VCIs.

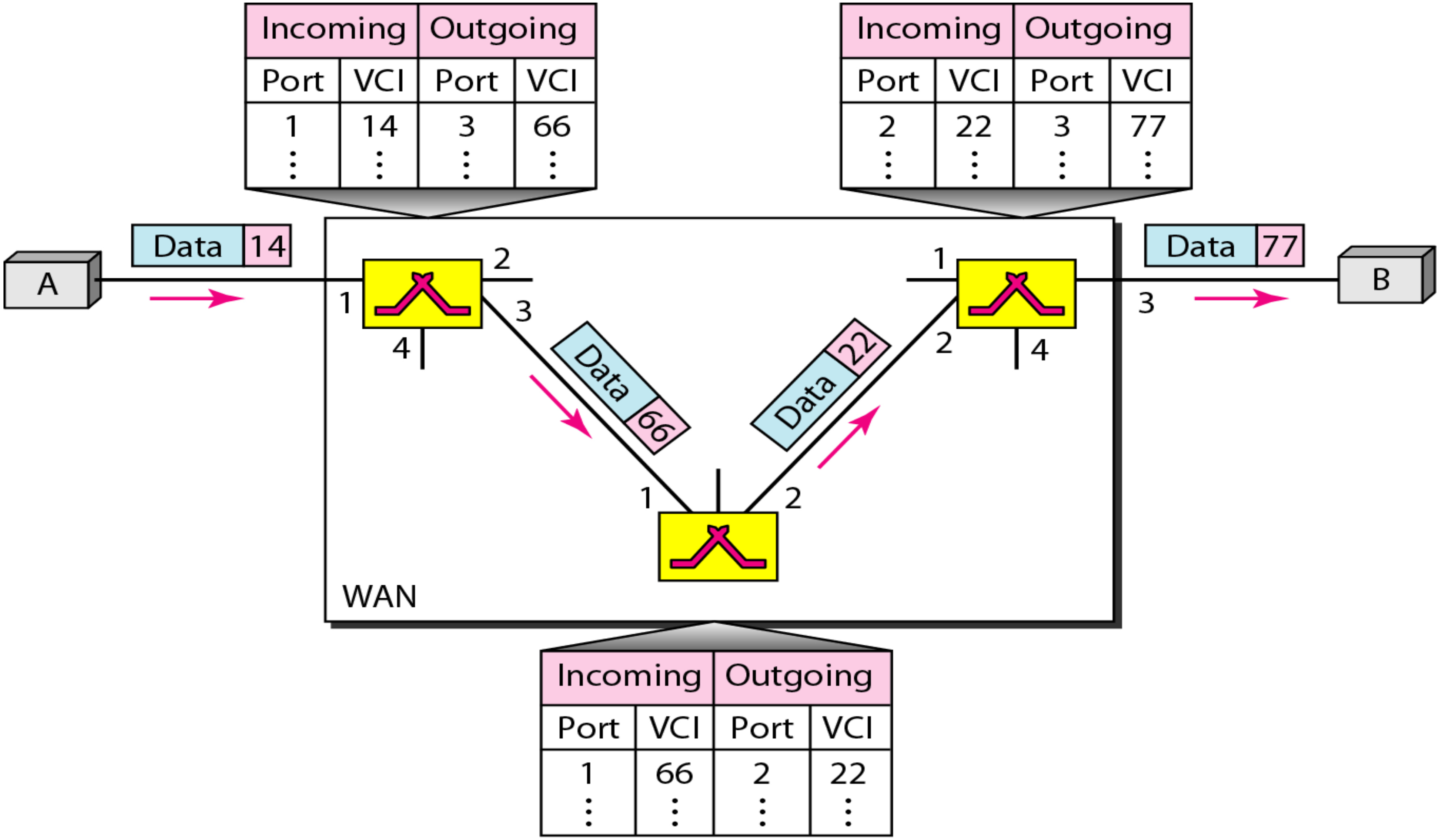


Switch and tables in a virtual-circuit network



Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	22
1	77	2	41

Source-to-destination data transfer in a virtual-circuit network



Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	66
⋮	⋮	⋮	⋮

Incoming		Outgoing	
Port	VCI	Port	VCI
2	22	3	77
⋮	⋮	⋮	⋮

Incoming		Outgoing	
Port	VCI	Port	VCI
1	66	2	22
⋮	⋮	⋮	⋮

Efficiency

The efficiency of a datagram network is better than that of a circuit-switched network

- Resources are allocated only when there are packets to be transferred.
- If a source sends a packet and there is a delay of a few minutes before another packet can be sent, the resources can be reallocated during these minutes for other packets from other sources.

Routing & Routing Algorithms

- The algorithms that choose the routes and the data structures that they use are a major area of network layer design
- **Routing algorithm**: is that part of the network layer software responsible for deciding which output line an incoming packet should be transmitted on
- It is sometimes useful to make a distinction between **routing**, which is making the decision which routes to use, and **forwarding**, which is what happens when a packet arrives.
- One can think of a router as having two processes inside it.
  - Forwarding: handles each packet as it arrives, looking up the outgoing line to use for it in the routing tables.
  - The other process is responsible for filling in and updating the routing tables. That is where the routing algorithm comes into play.

Static Versus Dynamic Routing

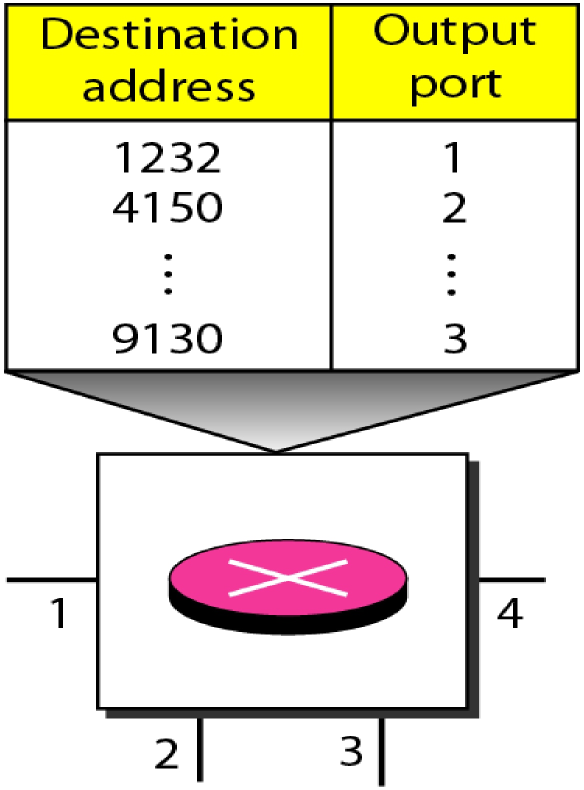
- **Static routes - When a network administrator manually enters information about a route, it is considered a static route.**
  - Only a network administrator can change this information. (That is, the router does not learn from, or update, its routing tables based on network events.)
  - Static routes allow for tight control of packets but are difficult to maintain and prone to human error.
- **Dynamic routes - Routers on a network can learn about possible routes and current route status from other routers in the network.**
  - Routers in dynamic routes learn about changes in the network without administrative intervention and automatically propagate them throughout the network.

Flat Versus Hierarchical Routing

- With flat networks, all routers must keep track of all other routers on the network. As networks grow, the amount of information contained in the routing tables increases.
- Although this method is simple, it can result in poor network performance because the number of routing updates traffic grows with each new router.
- Hierarchical networks segment routers into logical groupings. This arrangement simplifies routing tables and greatly reduces overhead traffic.

Routing Table

- If there are no setup or teardown phases, how are the packets routed to their destinations in a datagram network?
- In this type of network, each switch (or packet switch) has a routing table which is based on the destination address.
- The routing tables are dynamic and are updated periodically.
- The destination addresses and the corresponding forwarding output ports are recorded in the tables.



Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3

Routing & Routing Algorithms

- Routing is one of the fundamental aspects of networking.
- Routed networks are often large and complex, and it would be prohibitively difficult to manage and update network information on all routers all the time.
- Several algorithms have been developed to help address these difficulties. These algorithms allow the routers to learn about the network and then make decisions based on that information.
- To learn paths (or routes) through a network, and make decisions on where to send packets, a router use
  - Destination address - Typically the Internet Protocol (IP) address of the data's (packet) destination.
  - Source address - Where the information came from (typically an IP address).
  - Possible routes - Routes that can get information from its present location or source to some other location (the destination or closest known point).
  - Best route - The best path to the intended destination. ("Best" can mean many things.)
  - Status of routes - The current state of routes, which routers track to ensure timely delivery of information.

What Exactly Does "Best" Mean?

- Routers often make decisions about the best possible path to get information from a source to a destination.
- "Best," however, is loosely defined, and it depends on what is valued by the network.
- These measurements of value are referred to as metrics.
- Which metrics are valued by the network is determined by the network administrator. Several metrics are listed here:
  - Hop count - Number of times a packet goes through a router.
  - Delay time - Time required to reach the destination.
  - Reliability - Bit-error rate of each network link.
  - Maximum transmission unit (MTU) - Maximum message length (or packet size) allowed on the path.
  - Cost - Arbitrary value based on a network- administrator' determined value. Usually some combination of other metrics.

What Exactly Does "Best" Mean?

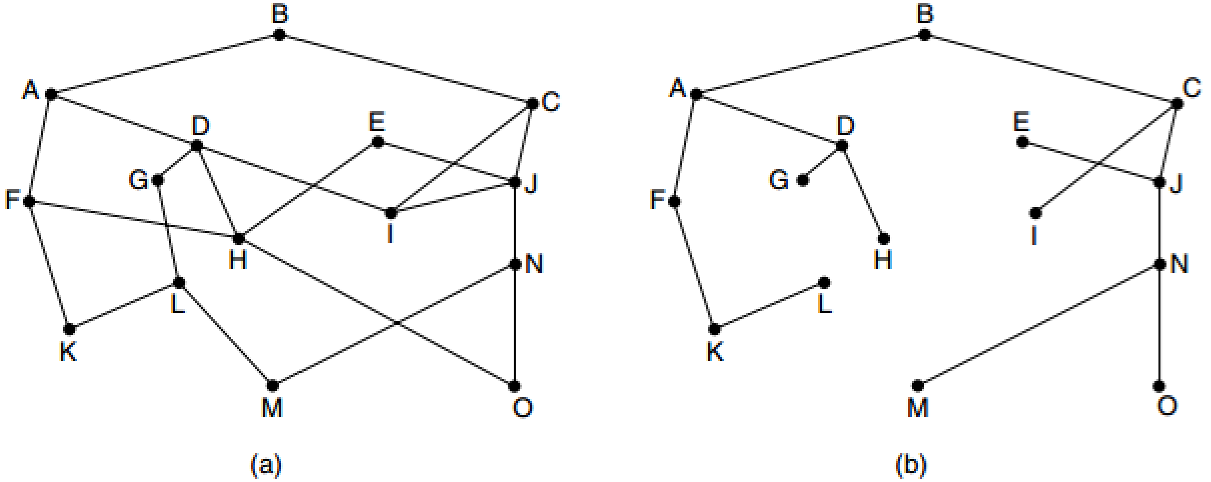
- One can make a general statement about optimal routes without regard to network topology or traffic.
- This statement is known as the optimality principle

  It states that if router J is on the optimal path from router I to router K, then the optimal path from J to K also falls along the same route.

- As a direct consequence of the optimality principle, we can see that the set of optimal routes from all sources to a given destination form a tree rooted at the destination. Such a tree is called a **sink tree**

What Exactly Does "Best" Mean?

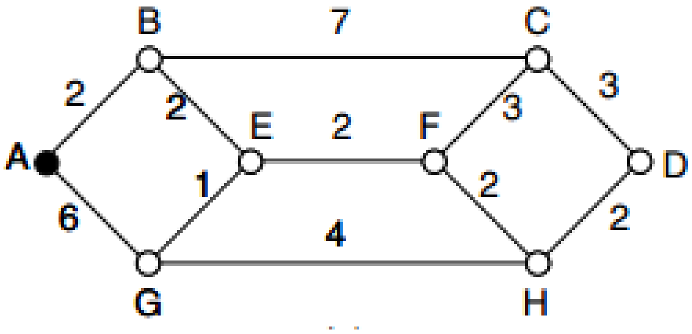
- Sink Tree is illustrated in Figure below, where the distance metric is the number of hops.
- The goal of all routing algorithms is to discover and use the sink trees for all routers.



(a) A network. (b) A sink tree for router B

Shortest Path Algorithm

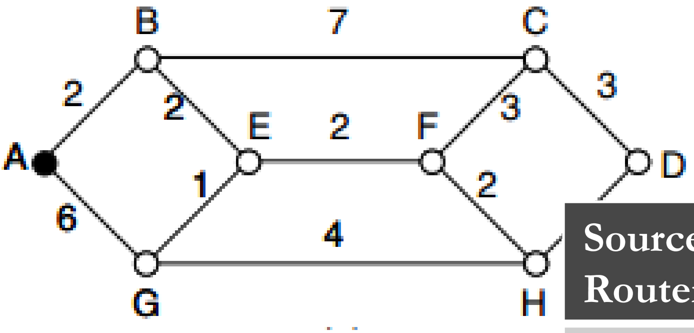
- The determination of the best route to a particular destination is normally based upon the shortest routing distance(or path cost) from the router in question
- The labels on the edges could be computed as a function of the distance, bandwidth, average traffic, communication cost, measured delay, and other factors



Example:

Build the routing table from the link costs and determine the shortest distance from router A to router D

Shortest Path Algorithm



Source Router	Destination Router	Shortest Distance	Best Path	Next Hop
A	B	2	A-B	B
A	C	9	A-B-C	B
A	D	12	A-B-C-D	B
B	G	3	B-E-G	E
B	H	6	B-E-F-H	E
C	G	6	C-F-E-G	F

Distance-Vector Versus Link-State Routing

- The two main classes of routing are distant vector routing and link-state routing.
- With distance-vector routing, routers share their routing table information with each other. Also referred to as "routing by rumor," each router provides and receives updates from its direct neighbor.
- The only information a router knows about a remote network is the distance or metric to reach that network and which path or interface to use to get there
- A distance vector describes the direction (port) and the distance (number of hops or other metric) to some other router.
- When a router receives information from another router, it increments whatever metric it is using. This process is called distance accumulation.
- Routers using this method know the distance between any two points in the network, but they do not know the exact topology of an internetwork.

Distance-Vector Versus Link-State Routing

- Network discovery is the process of learning about indirectly connected routers. During network discovery, routers accumulate metrics and learn the best paths to various destinations in the network.
- With link-state routing, also known as shortest path first (SPF), each router maintains a database of topology information for the entire network.
- Link-state routing provides better scaling than distance-vector routing because it only sends updates when there is a change in the network, and then it only sends information specific to the change that occurred.
- A router configured with a link-state routing protocol can create a "complete view" or topology of the network by gathering information from all of the other routers.
- Distance vector uses regular updates and sends the whole routing table every time. Link-state routing also uses a hierarchical model, limiting the scope of route changes that occur.

WAN Technology Options

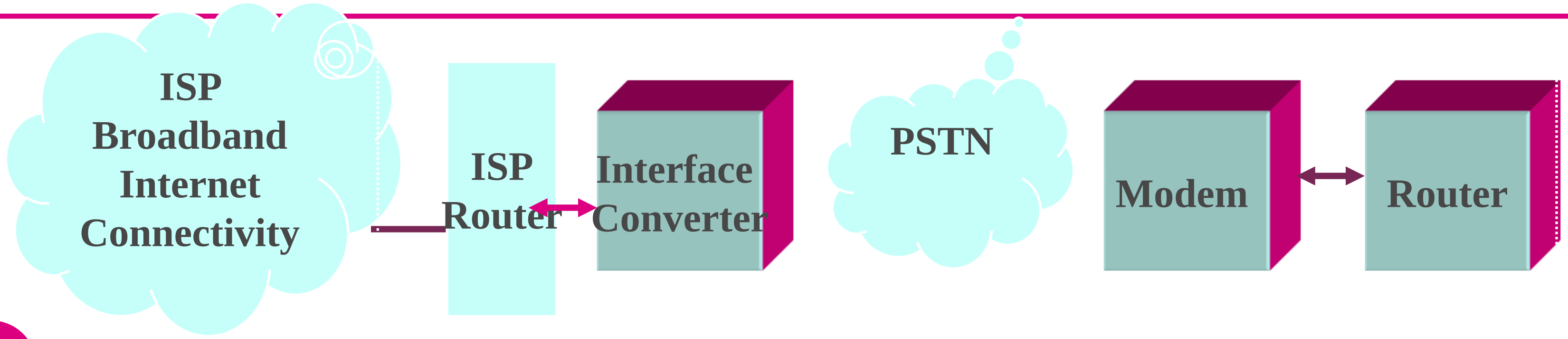
- Dial-up
- Leased Line
- ISDN
- DSL
- X.25 technology
- Frame relay and virtual circuit
- ATM Technology
- Cable Modem
- Microwave Point-to-Point Link
- VSAT

Dial-up

- Uses POTS (Plain Old Telephone System)
- Provides a low cost need based access.
- Bandwidth 33.6 /56 Kbps.
- On the Customer End: Modem is connected to a Telephone Line
- On the Service Provider End: Remote Access Server (RAS) is connected to Telephone Lines (33.6 Kbps connectivity) or E1/R2 Line (56 Kbps connectivity)
- RAS provide dial in connectivity, authentication and metering.
- Achievable bandwidth depends on the line quality.

Leased Line

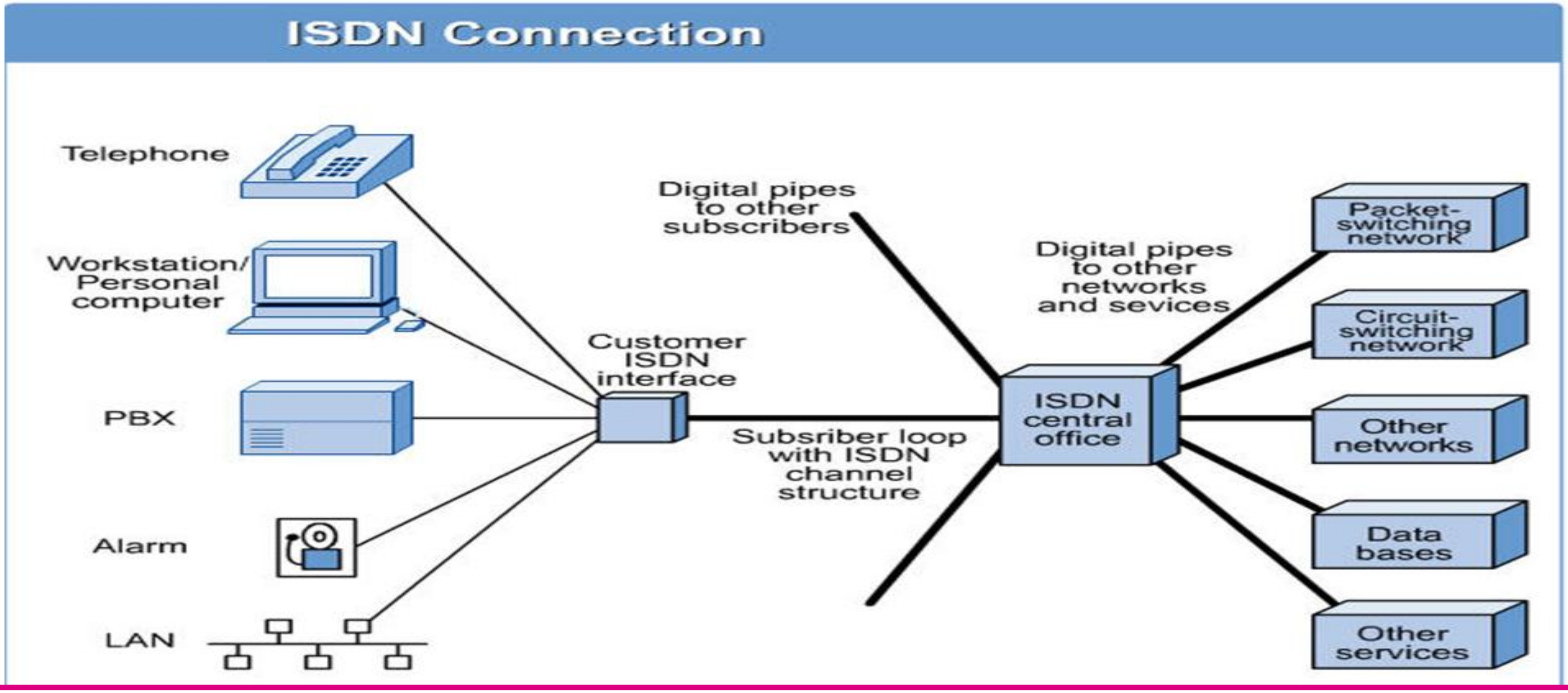
- Used to provide point-to-point dedicated network connectivity.
- Each side of the line permanently connected to the other, unlike dial-up connections, a leased line is always active.
- Connecting two locations in exchange for a monthly rent, the fee for the connection is a fixed monthly rate.
- Typically, leased lines are used by businesses to connect geographically distant offices
- Analog leased line can provide maximum bandwidth of 9.6 Kbps.
- Digital leased lines can provide bandwidths :
  64 Kbps, 2 Mbps (E1), 8 Mbps (E2), 34 Mbps (E3) …



ISDN (Integrated Service Digital Network)

- Another alternative to using analog telephones lines
- It is a set of communications standards for simultaneous digital transmission of voice, video, data, and other network services over the traditional circuits of the public switched telephone network.
- Speed is one advantage ISDN has over telephone line connections.
- ISDN network is a switched digital network consisting of ISDN Switches.
- ISDN user accesses network through a set of standard interfaces provided by ISDN User Interfaces.

ISDN


ISDN Connection
Telephone
Workstation/ Personal computer
PBX
Alarm
LAN
Customer ISDN interface
Digital pipes to other subscribers
Subsriber loop with ISDN channel structure
ISDN central office
Digital pipes to other networks and sevices
Packet-switching network
Circuit-switching network
Other networks
Data bases
Other services

Two types of user access are defined

- Basic Access - Consists of two 64Kbps user channels (B channel) and one 16Kbps signal channel (timing and alarm channel) (D channel) providing service at 144 Kbps.
- Primary access - Consists of thirty 64Kbps user channels (B channels) and a 64 Kbps signal channel (timing and alarm channel) (D channel) providing service at 2.048Mbps (One 64 Kbps channel is used for Framing and Synchronization).

Digital Subscriber Line (DSL)

- Digital Subscriber Line (DSL) uses the Ordinary Telephone line and is an always-on technology. This means there is no need to dial up each time to connect to the Internet.
- Because DSL is highly dependent upon noise levels, a subscriber cannot be any more than 5.5 kilometers (2-3 miles) from the DSL Exchange
- Service can be symmetric, in which downstream and upstream speeds are identical, or asymmetric in which downstream speed is faster than upstream speed.
- DSL comes in several varieties:
  - Asymmetric DSL (ADSL)
  - High Data Rate DSL (HDSL)
  - Symmetric DSL (SDSL)
  - Very High Data Rate DSL (VDSL)

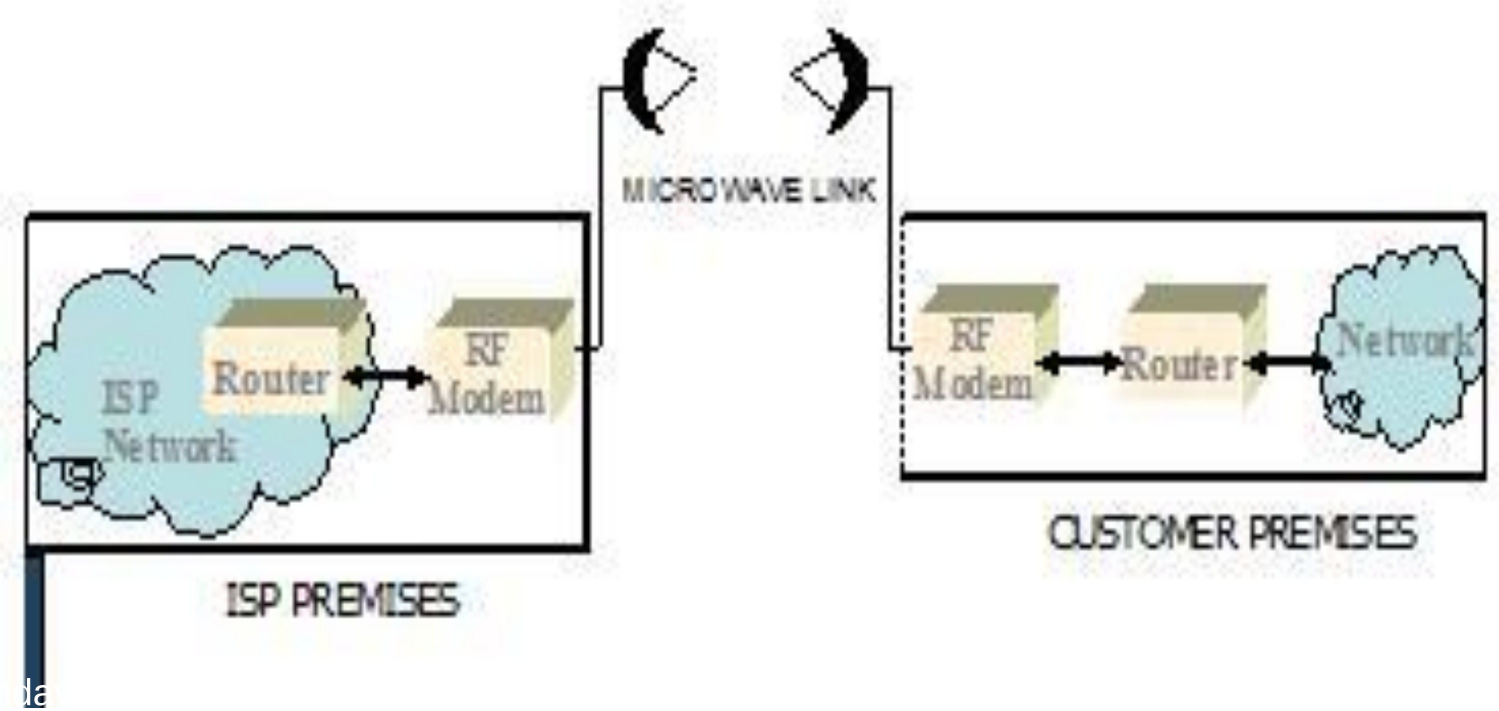
Cable Modems

- The cable modem connects a computer to the cable company network through the same coaxial cabling that feeds cable TV (CATV) signals to a television set.
- Uses Cable Modem at Home End and CMTS (Cable Modem Termination System) at Head End.
- Characteristics:
  - Shared bandwidth technology
  - 10 Mbps to 30 Mbps downstream
  - 128Kbps-3 Mbps upstream
  - Maximum Distance from provider to
  - customer site: 30 miles

- Cable modems are primarily used to deliver broadband Internet access in the form of cable Internet, taking advantage of the high bandwidth of a cable television network.

Point-to-Point Microwave Link

- Typically 80-100 MHz Band or 5 GHz Radio Link band
- 2.4 GHz WiFi links are becoming popular
- Requires Line of Sight



VSAT

- **Very Small Aperture Terminal (VSAT) provide communication between two nodes through a powerful Earth station called a Hub.**
- **If two terminals want to communicate, they send their messages to the satellite, which sends it to the Hub and the Hub then broadcasts the message through the satellite.**
- **Typical Bandwidth offered is 9.6/19.2/32/64/128/256/512 Kbps.**

- **Each satellite sends and receives over two bands**
  - **Uplink: From the earth to the satellite**
  - **Downlink: From the satellite to the earth**
- **Satellite frequency bands**

Band	*Downlink*	*Uplink*
C	3.7-4.2 GHz	5.925-6.425 GHz
Ku	11.7-12.2 GHz	14-14.5 GHz

- **Ku-band based networks, are used primarily in Europe and North America and utilize the smaller sizes of VSAT antennas.**
- **C-band, used extensively in Asia, Africa and Latin America, require larger antenna.**

VSAT

- VSATs are most commonly used to transmit narrowband data (point of sale transactions such as credit card, polling or RFID data), or broadband data (for the provision of Satellite Internet access to remote locations, VoIP or video).
- VSATs are also used for transportable, on-the-move (utilizing phased array antennas) or mobile maritime communications.